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SOLAR ENERGY TO HEAT AND COOL A NEW NASA LANGLEY OFFICE BUILDING

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ABSTRACT

A solar heating and cooling system will be installed at a new NASA office building. The objective of this project is to establish a full-scale working test-bed facility to investigate solar energy for heating and cooling buildings. The energy collected will provide between 80 and 100 percent of the heating and cooling requirements during the cool months and between one-half and two-thrust of the cooling requirements in the summer. Thermal energy storage will be provided to bridge the gap between cloudy and clear days.

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SOLAR ENERGY TO HEAT AND COOL A NEW NASA LANGLEY OFFICE BUILDING

by William L. Maag

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SUMMARY

The NASA Lewis Research Center is investigating the use of solar energy to provide a portion of this nation's energy requirements. In a joint effort with the NASA Langley Research Center, a solar heating and cooling system will be installed at a new NASA office building to be constructed at Langley. The objective of this project is to establish a full-scale working test-bed facility to investigate solar energy for heating and cooling buildings. Results will provide technical and operational information required to establish solar collector performance and assess the use of solar energy for this application.

The building heating and cooling system will operate on 160 to 220° F hot water generated from solar energy or from a steam utility system. The solar system will initially be designed for 15 000 square feet of collector surface area, located directly adjacent to the building. Analysis shows that the system could perform at an overall thermal efficiency between 30 and 50 percent. The energy collected at these conditions will provide between 80 and 100 percent of the heating and cooling requirements during the cool months and between one-half and two-thirds of the cooling requirements in the summer. Thermal energy storage will be provided to bridge the gap between cloudy days and clear days.

INTRODUCTION

The NASA Lewis Research Center is investigating the use of solar energy to provide a portion of this nation's energy requirements. Although solar energy is abundant, it is received on earth as a low temperature and low flux energy source. NASA's goal is to find and develop

useful applications for solar energy. One application that appears suitable for this type of energy is heating and cooling of buildings, which currently accounts for about 20 percent of the nation's consumption of fossil fuels. The use of clean solar energy for a significant portion of this need would be beneficial both in conserving fossil fuel and in reducing pollution.

NASA plans to provide a solar heating and cooling system for a new NASA office building currently scheduled for construction in CY 1974 and 1975 at the Langley Research Center at Hampton, Virginia. A solar hot water system will be installed as a part of the building's conventional heating-ventilating-air conditioning (HVAC) system, and is scheduled to be operational during CY 1975. The objective of this project is to establish a full-scale, working test bed facility to investigate sloar energy systems, particularly in areas where NASA has experience, such as thermal design, selective coating technology, and thermodynamic energy systems. The solar system will be capable of accepting up to 16 different types of solar collectors, thus serving as a full-scale test bed for both state-of-the-art and advanced solar collector technology.

Results from this project will provide technical and operational information that is necessary to assess the feasibility of using solar energy for heating and cooling in various geographical locations in the United States. This information will be part of the national solar energy activity in which NSF and other government agencies are participating.

This report describes the HVAC energy requirements for the Langley Building and analyzes the method of utilizing solar energy to meet a significant portion of those requirements.

BUILDING DESCRIPTION

The new Langley System Engineering Building (SEB), shown in figure 1, was chosen for this project. It will be a single story structure enclosing 53 000 square feet of floor space for 350 engineering personnel. The building was originally designed by Langley with a conventional HVAC system using compression-cycle air conditioning. As part of NASA's energy conservation program, the Langley design includes an activated charcoal

filtering system that permits the ventilation air requirements to be reduced 75 percent to 5.5 cubic feet per minute per person which reduces the air conditioning load about 10 percent.

To accept solar energy, the compression-cycle air conditioner will be replaced with an absorption-cycle air conditioner which can operate with hot water supplied by the Langley utility system or generated from solar heat. An area adjacent to the building (fig. 2) will be used to place the solar collectors, storage tanks, and piping and control system. The heating ventilating and air conditioning (HVAC) system is illustrated schematically in figure 3. Ventilation air at 60° F is circulated through the building at a rate of 5.5 cubic feet per minute per person. This air receives the heat load produced by people, lights, transmission, infiltration, etc., and is either partially exhausted to the outside or recirculated through charcoal filters for reuse. When the outside air temperature is above 60° F, the ventilation air is cooled in a heat exchanger that is supplied with chilled water at 45° F from the absorption chiller. Heat losses from the building surfaces during the winter months are balanced with heat supplied from baseboard heaters. The building is zoned for optimum utilization of heating.

The HVAC system can be operated with hot water produced either from solar collectors or from a heat exchanger operated with steam from the Langley utility system. The energy is utilized in two stages. In the temperature range between 200° and 240° F, the hot water operates an absorption cycle (lithium bromide-water) chiller that will produce 50 to 150 tons respectively of cooling in the form of chilled water to cool the ventilation air. The hot water leaves the absorption unit at a minimum temperature of 180° F which is sufficient to then provide heat to the building through the baseboard convectors before it is returned to the heat source at a minimum temperature of 140° F. The system can operate separately to provide either heating or cooling, and simultaneously for both.

BUILDING ENERGY REQUIREMENTS

The heating and cooling requirements for the SEB were calculated by Langley for each hour of a typical year, using the U.S. Post Office

Department - Equipment and Energy Consumption Analysis computor program. The results of this calculation, based on weather data for the year 1966, are shown in figure 4. The total annual energy consumption is 4.2 billion Btu's, of which 80 percent is required for cooling and 20 percent for heating. Note that for the southern Virginia area, cooling is necessary every month of the year, while heating is required for only eight months. Figure 5 shows the energy consumption profile for the design day based on 94° F outside and 75° F inside temperatures with a lighting load of 4 watts per square foot. This establishes the absorption air conditioning capacity at 150 tons, which corresponds to a peak energy requirement of 2.7 million Btu per hour.

SOLAR ENERGY AVAILABILITY

The average daily incidence of solar energy on a horizontal surface at ground level in the continental United States is about 1400 Btu/day-ft^2 (17 W-ft^2). The instantaneous solar flux for any particular location depends on the time of day, time of year, latitude and cloud cover. Figure 6 shows the range of daily average solar radiation for the United States over a typical year. The maximum curve represents the desert Southwest and the minimum curve is typical of the populous Northeast. Weather Bureau data from recording stations near the Langley area are indicated and used to size the solar HVAC system.

The solar radiation data used herein are the total radiation (direct and diffuse) incident on a horizontal surface. The amount of this flux that can be collected and recovered depends primarily on the angle of incidence and the thermal efficiency of the collection system. For a fixed, flat-plate solar collector surface, and geographical location, there is an optimum angle of tilt toward the equator that will maximize the total solar flux density over a yearly period. For the Langely area latitude, an angle of tilt from the horizontal to the south of 30° is near optimum, although any tilt angle between 15° and 45° results in flux changes of less than 10 percent below optimum.

This effict of tilt angle is illustrated in figure 7, using the Langley data from figure 6 translated into monthly averages. A 30° tilt angle increases the total yearly incident radiation by almost 30 percent over the horizontal flux. Tilt angles between 15° and 45° would not greatly change the total yearly radiation amount, but would change the shape of the profile. A 15° tilt angle increases the summer incident radiation about 10 percent over the 30° value with a corresponding decrease in the winter radiation. A 45° tilt angle has just the opposite effect by increasing winter values while reducing the summer flux.

SOLAR ENERGY COLLECTION

The amount of solar energy that can be recovered is very dependent on the efficiency of the collector that is used. This section discusses the effects of various collector properties on the amount of recoverable energy, and determines the range of collector thermal efficiency that should be applicable for the Langley project. The following designs and operating factors will be considered: absorber plate absorbtivity, absorber plate emissivity, number of glass cover plates, and magnitude of incident solar heat flux.

Solar radiant energy can be converted to heat by providing an absorbing surface for the incident flux. If the surface resembles a black body, more than 90 percent of the radiant energy is absorbed and converted to heat. If conduction and convection heat-transfer losses from the surface to the surroundings are minimized, typically by a glass covering that is transparent to the incident solar flux and encloses a dead-air space or a vacuum enviroment, then radiation heat transfer will be controlling and the absorber will reach some equilibrium temperature. The magnitude of the equilibrium temperature is determined primarily by the emittance characteristics of the surface and the opaqueness of the glass cover to the long wavelength radiation emitted by the absorber. Special coatings can be applied to the absorber surface to enhance absorptivity (α) and to minimize emissivity (ϵ) so that the α/ϵ ratio is about 10. For well-insulated solar collectors with 95 percent absorptivity and 10 percent emissivity, the equilibrium temperature should

be about 500° F (ref. 1). By introducing a fluid, such as water, into contact with the absorbing surface, the thermal energy collected from the sun can be transferred for useful work. The thermal efficiency for a given solar collector design irradiated at a constant solar flux is inversely proportional to the temperature of the absorber surface (ref. 2). Figure 8 shows this relationship for four collector designs that could be used to produce hot water. The conditions for this comparison are total normal solar radiation of 300 Btu/hr-ft^2 representing a high-noon condition, ambient temperature of 70° F and wind speed of 15 miles per hour. The absorptivity of the absorber surface is 95 percent but the emissivity is varied to give an α/ϵ ratio of either 1 or 10. The insulation characteristics included a single and double glass cover with an air environment and a single glass cover with a vacuum environment. This comparison illustrates the importance of low emissivity and good insulation for high temperature solar collectors.

The actual working solar collectors for this application will operate at conditions somewhat different from those of figure 8. The actual collector will view a solar flux that varies with the time of day, time of year and the angle of tilt toward the equator. The plate temperature will vary between about 190° F for winter operation and 230° F for summer operation. All of these factors combine to give a more realistic collector efficiency than that indicated by figure 8.

Collectors 2 and 3 represent the performance range that appears most feasible with current technology for this application. From the information of figure 8, the rate of radiation heat loss from these collectors was determined as a function of plate temperature. Assuming this heat loss is independent of solar flux, it can be used to evaluate the relationship between incident flux and collector thermal efficiency for these two collectors operating at plate temperatures corresponding to summer and winter conditions. Figure 9 shows that for a given collector design operating at a required absorber plate temperature, the thermal efficiency is determined by the magnitude of the solar flux. There is a minimum flux that will just equal the loses from the collector resulting in zero efficiency and producing no useful energy.

The variation of direct solar flux incident on an absorber surface tilted 30^0 toward the equator for clear winter and clear summer days at the Langley Research Center in Virginia is shown in figure 10 (ref. 3). The solar flux value from figure 9, that represent zero efficiency for collector 2 is indicated. Figure 10 illustrates that useful energy can be collected over a period of about six hours on a clear winter day and for about eight hours on a clear summer day. The collector efficiency varies throughout the day, starting at zero between 8 a.m. and 9 a.m. in the morning, reaching a peak at noon (sun time), and decreasing to zero again at late afternoon. The average solar flux for the six hour winter day period and the eight hour summer day period is 233 and 246 Btu/hr-ft^2 respectively. Thise values identified on figure 9, indicates that the average thermal efficiency is about 45 percent for collector 2 and about 65 percent for collector 3. The system thermal efficiency will be less than these values by the amount of any additional heat losses, such as losses from the solar piping systems connecting the collectors to the building HVAC system.

SOLAR HVAC SYSTEM

The solar HVAC system consists of two parts - the solar collectors and the piping, pumping and storage network required to transfer the recovered energy to the location where it is used. The design capacity of the system is determined by comparing the building energy requirements with the amount of solar energy that can be collected for the same time period. Since there will usually be a mismatch regardless of whether the comparison is based on an hourly, daily or monthly time period, it is necessary to compromise the system size to supply some fraction of the energy requirements over a season or year. This comparison was made on a monthly basis because the availability of solar energy can be reliably predicted for this time period. Storage will be used to even out the mismatches that occur for hourly and daily time periods.

The thermal efficiency for the solar system was assumed to be in the range between 30 and 50 percent. This was determined by taking the

average efficiency of the collector types indicated in figure 9 and assuming that heat losses through the piping and storage tank insulation will account for an additional 15 percent reduction in overall efficiency. Preliminary insulation calculations indicated that this magnitude of losses seems reasonable.

Figure 11 shows the effect of thermal efficiency on the amount of solar energy that can be collected by a surface tilted 30° toward the equator. By dividing the values shown on these curves into the building energy requirements of figure 4, the collector surface area required for each month's energy needs was determined. A compromise area of 15 000 square feet of collector surface was determined to be adequate for this application. The energy match for the system operating between 30 and 50 percent thermal efficiency is shown in figure 12.

This 15 000 square foot collector area will provide most of the heating and cooling requirements during the late fall, winter and early spring months of the year, and between one-half and two-thirds of the cooling requirements during the summer months. There will be days and perhaps weeks during which the solar system will handle all of the heating and cooling requirements with excess energy diverted to storage. Storage will bridge some of the gaps between cloudy days and clear days. Therefore, this size should be sufficient to demonstrate operation of the solar heating and cooling system for all modes of operation, i.e., heating only, cooling only, heating and cooling at the same time and switching from one mode of operation to another. Furthermore, if additional area is desired in the future, space is available to expand the collector field to 40 000 square feet of collector surface area.

CONCLUDING REMARKS

Analysis indicates that solar energy could be used to heat and cool a new 53 000 square foot office building at the NASA Langley Research Center in Hampton, Virginia. A match of the building energy require-

ments with the solar energy availability shows that a solar HVAC system sized for 15 000 square feet of collector surface area should provide between 80 and 100 percent of the heating and cooling requirements during the cool months and between one-half and two-thirds of the cooling requirements in the summer. The analysis assumes a solar system thermal efficiency between 30 and 50 percent providing hot water up to 220^{o} F for operating conventional HVAC equipment, including an absorption-cycle air conditioner.

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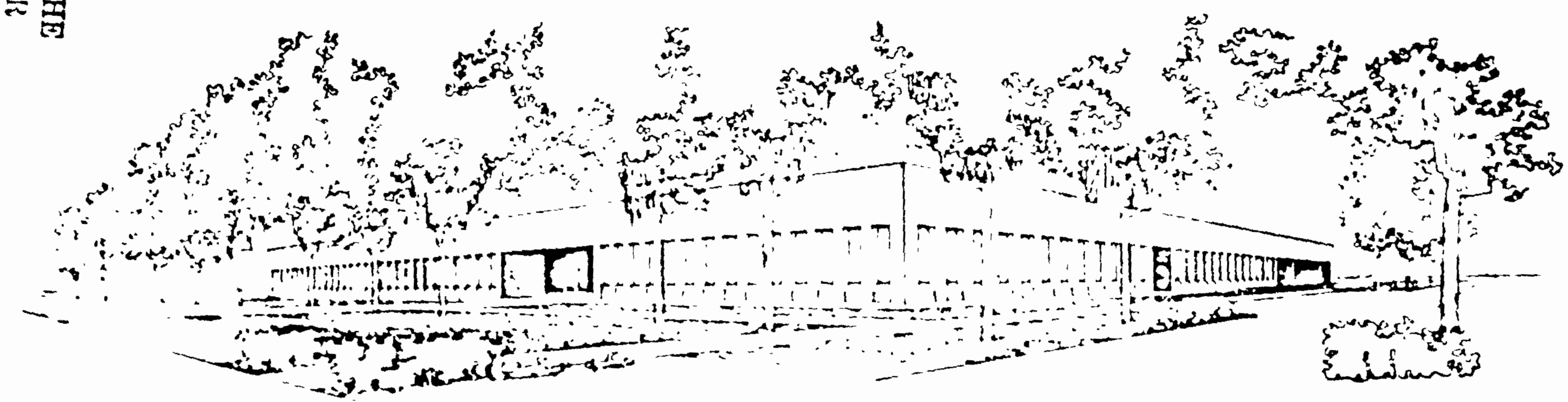
1. Yellott, J. I.: Power From Solar Energy, Trans. ASME, vol. 79, Aug. 1957, pp. 1349-1359.
2. Simon, F. F. ; and Harlamert, P.: Flat-Plate Collector Performance Evaluation, the Case for a Solar Simulation Approach. NASA TM X 71427, 1973.
3. ASHRAE Handbook of Fundamentals. American Society of Heating, Refrigeration and Air-Conditioning Engineers, 1972.

SYSTEMS ENGINEERING BUILDING
LANGLEY RESEARCH CENTER



PERSPECTIVE

FIGURE 1

SOLAR COLLECTOR SYSTEM

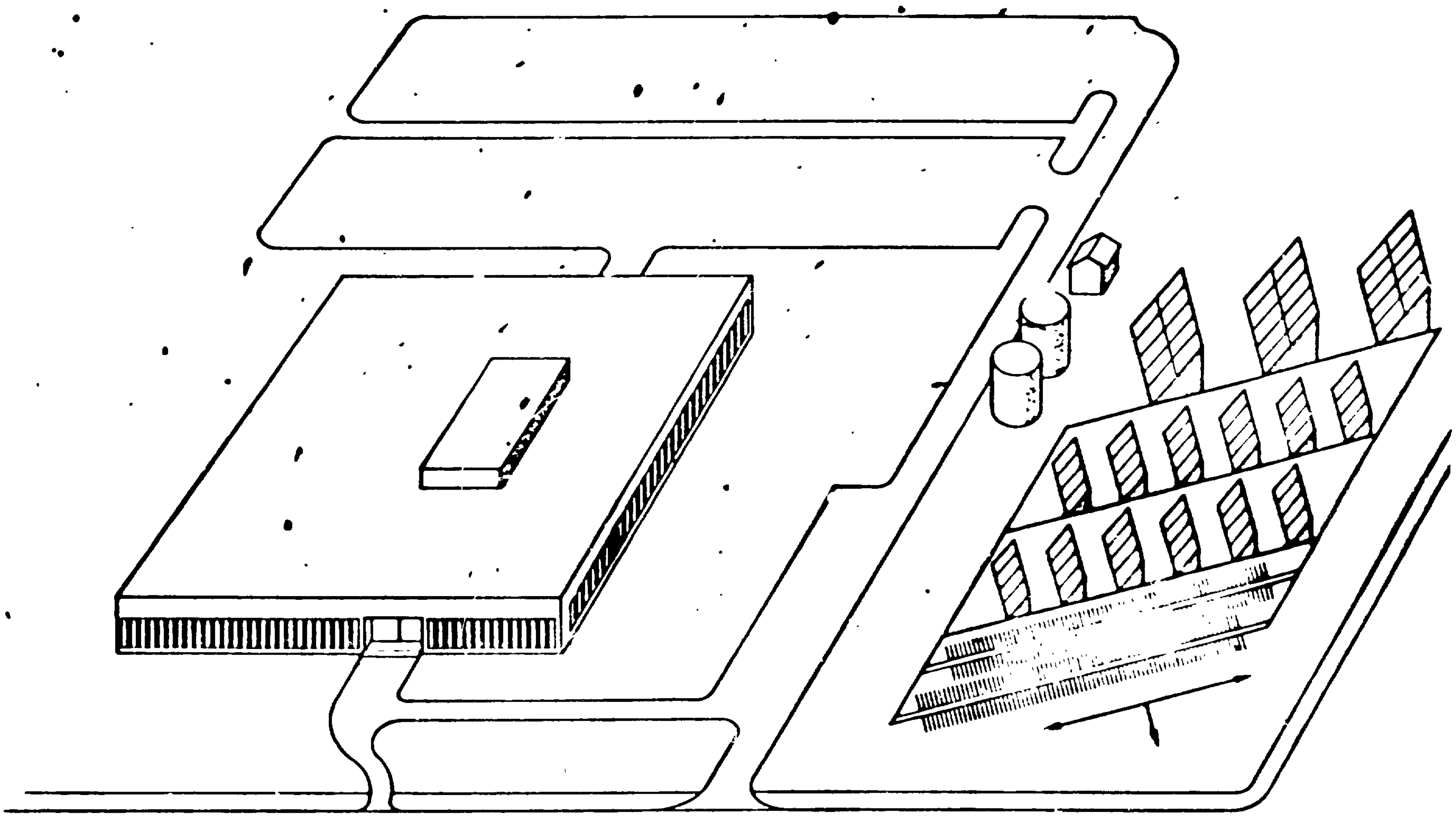


FIGURE 2

SYSTEMS ENGINEERING BUILDING USING SOLAR ENERGY

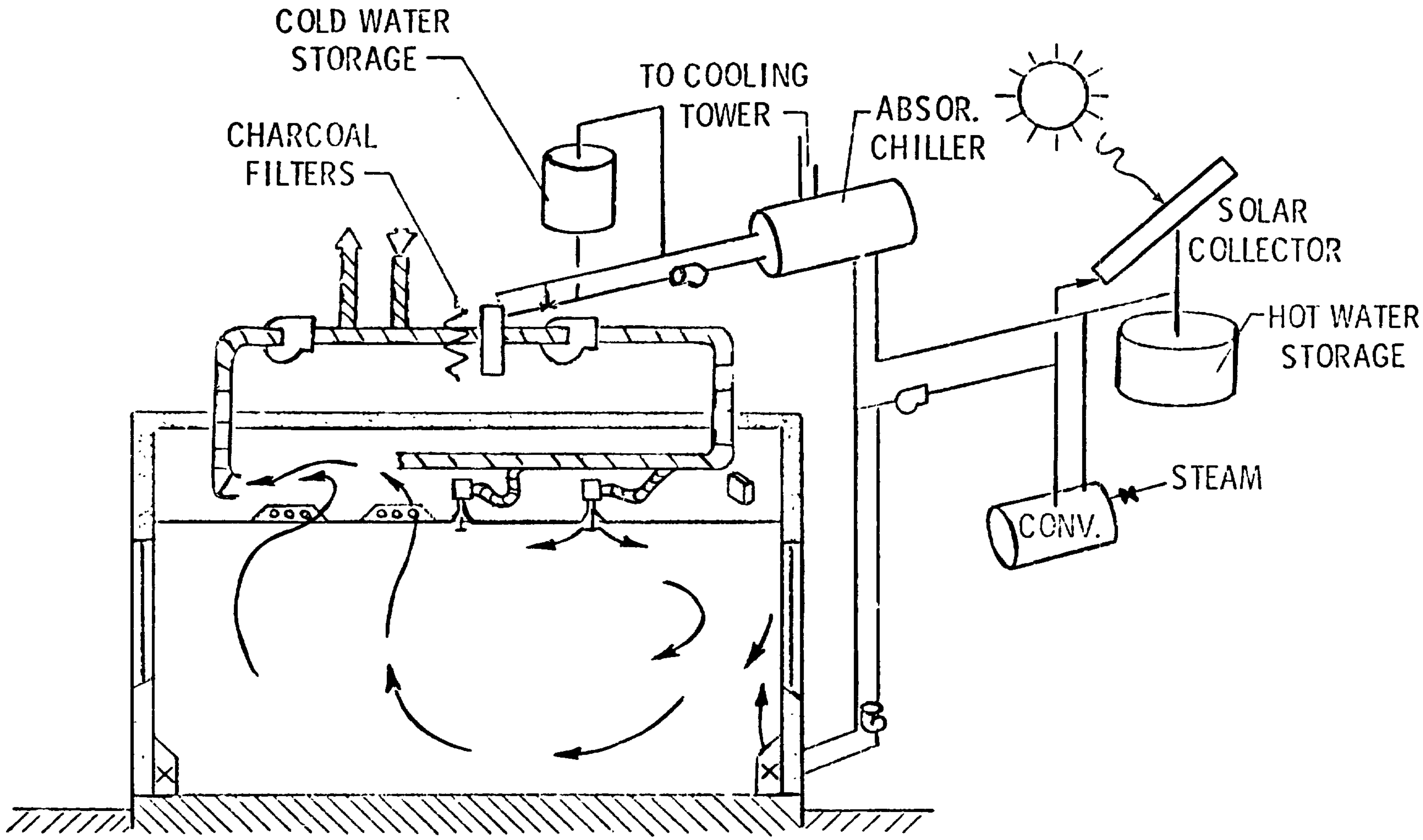


FIGURE 3

FIGURE 4

YEARLY

LANGLEY BUILDING

HVAC REQUIREMENTS

YEARLY TOTAL: 4,194 MBTU
80 % COOLING
20 % HEATING

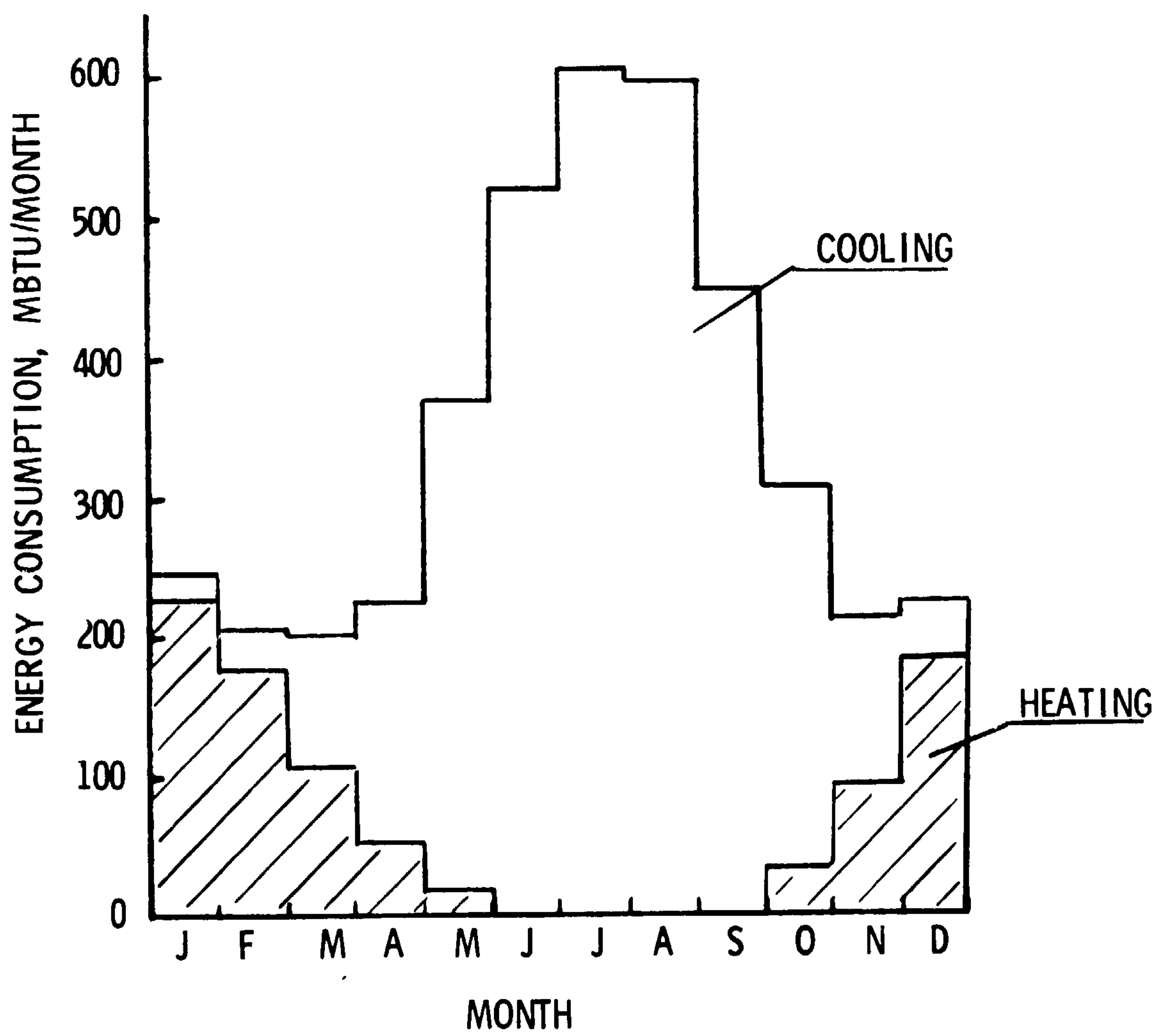


FIGURE 5

DAILY ENERGY CONSUMPTION FOR THE LANGLEY BUILDING

AIR CONDITIONING LOAD BASED ON A DESIGN DAY

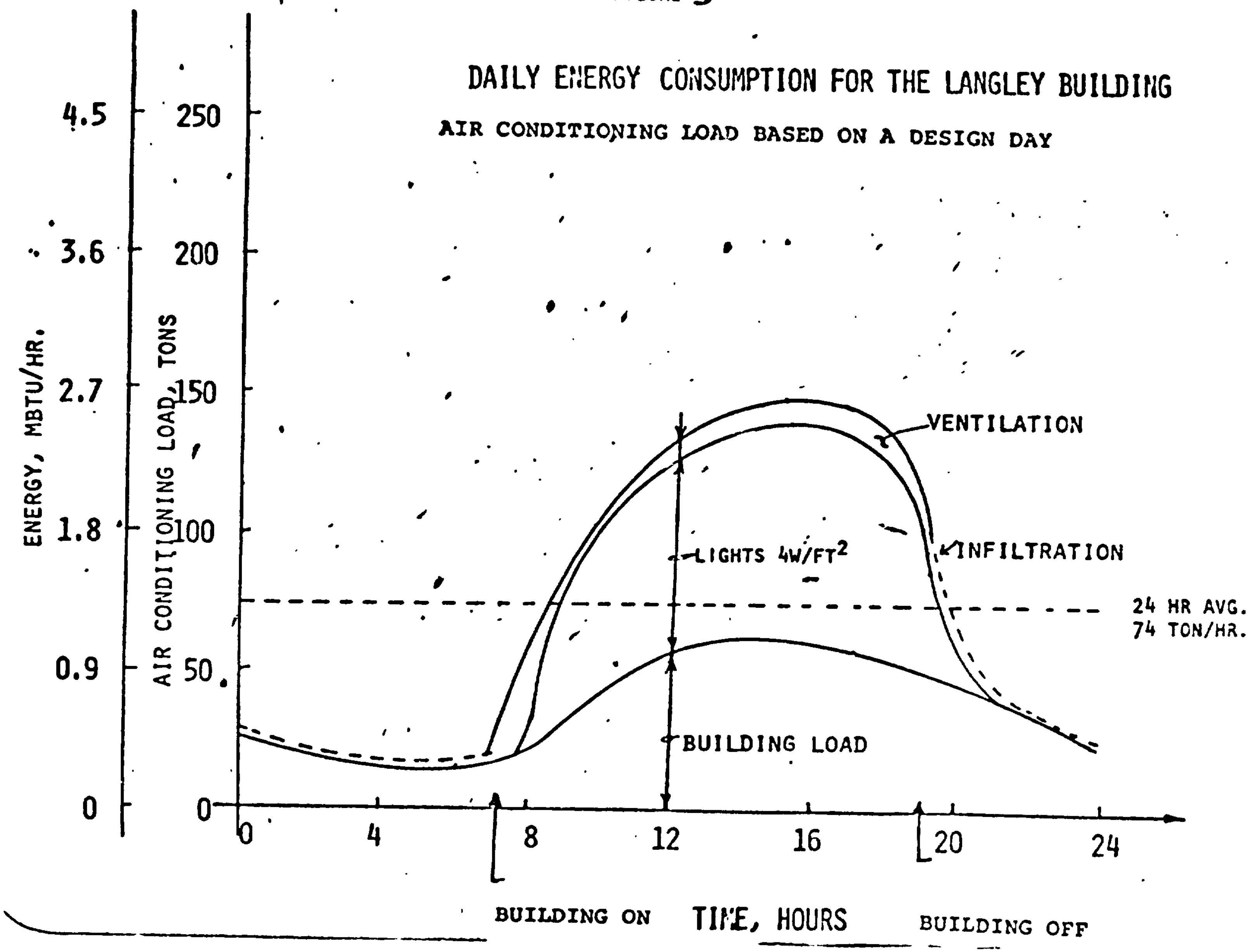


Figure 6

AVERAGE DAILY TOTAL RADIATION FOR U.S.

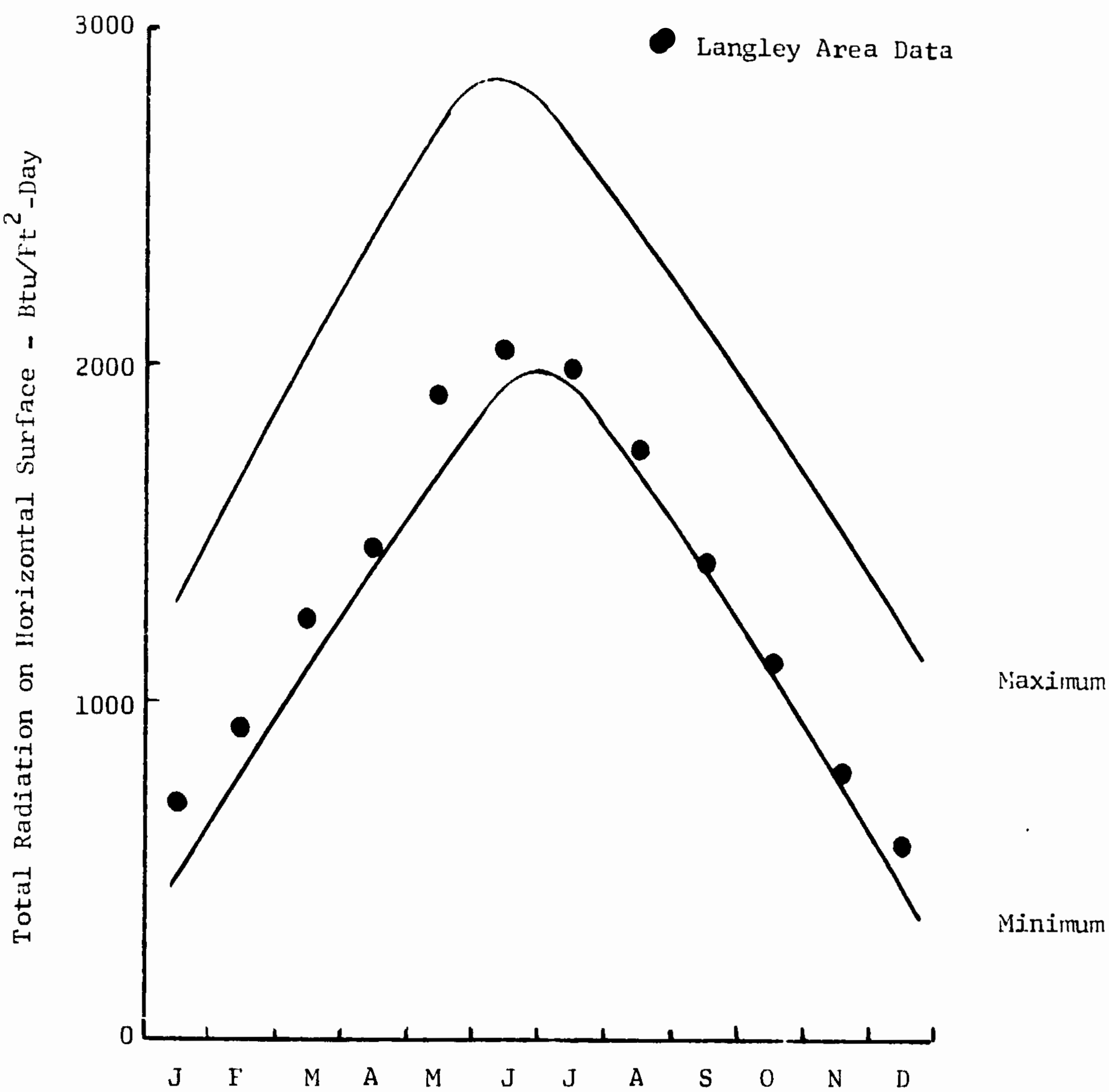


FIGURE 7

LANGLEY SEB

SOLAR ENERGY AVAILABILITY

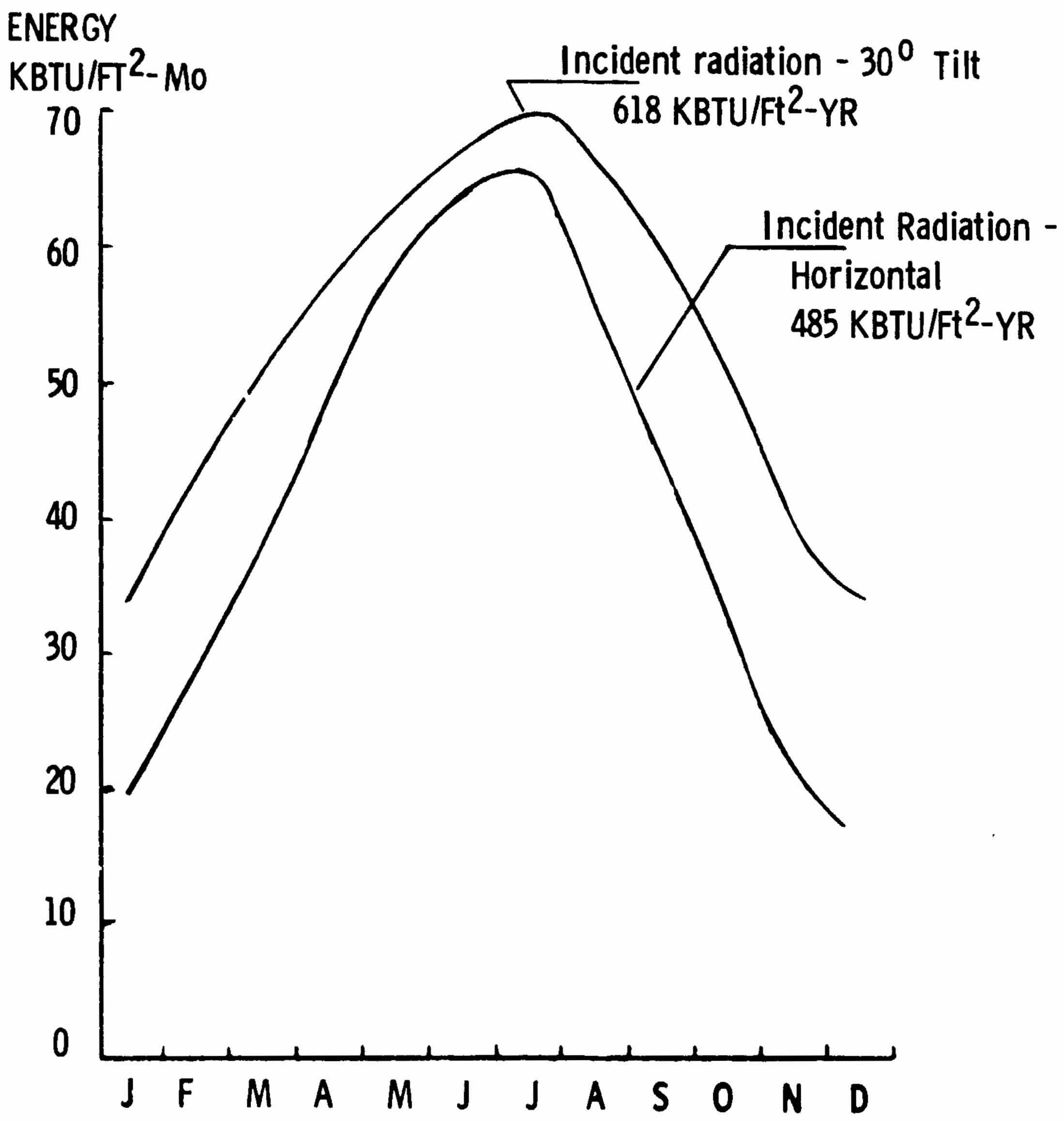


Figure 8

EFFICIENCY OF VARIOUS COLLECTOR TYPES

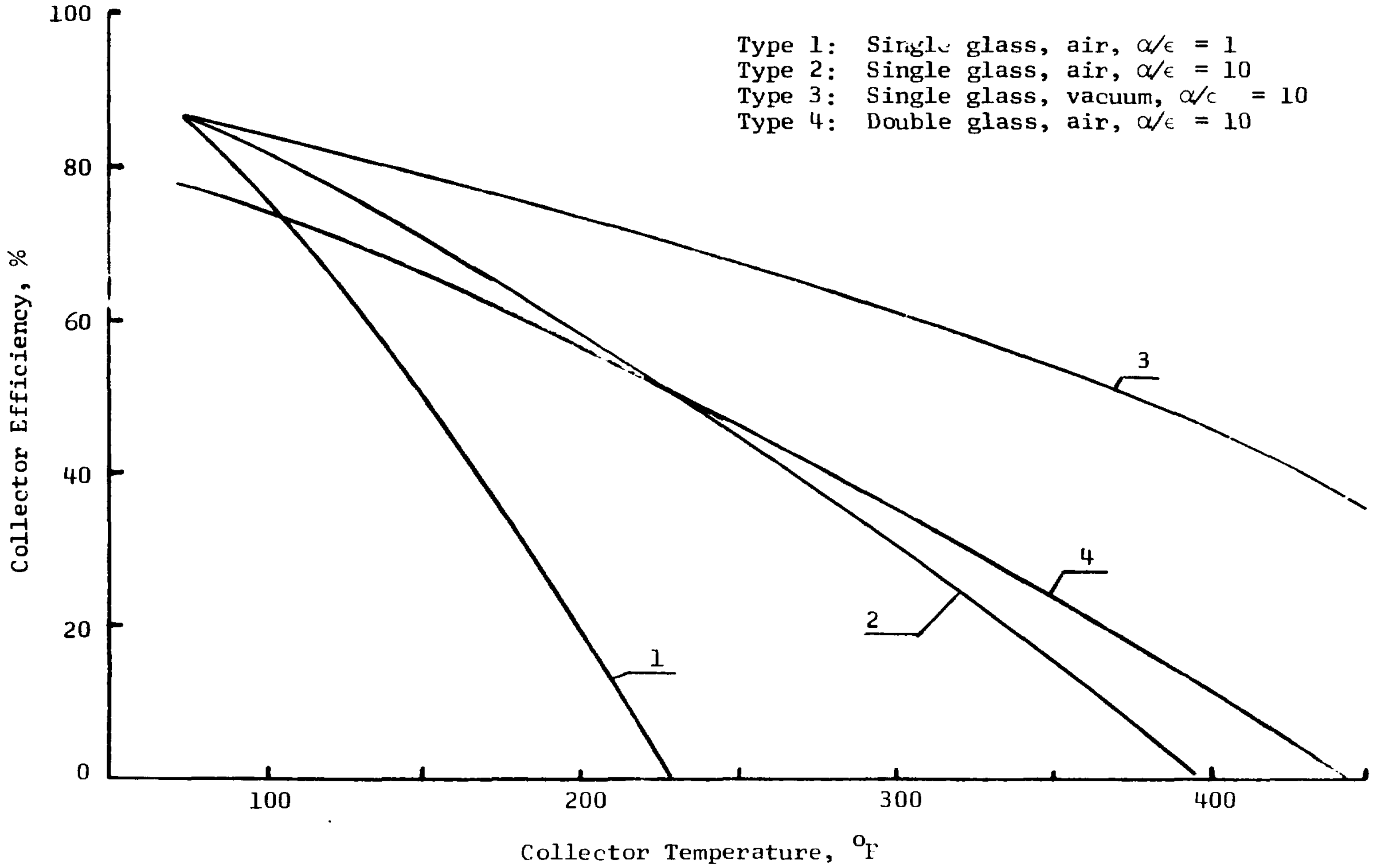


Figure 9

INCIDENT FLUX-EFFICIENCY RELATIONSHIP

FOR TYPICAL OPERATING CONDITIONS

	Winter	Summer
Plate Temp., °F	190	230
Flux, Btu/Hr-ft^2	233	246

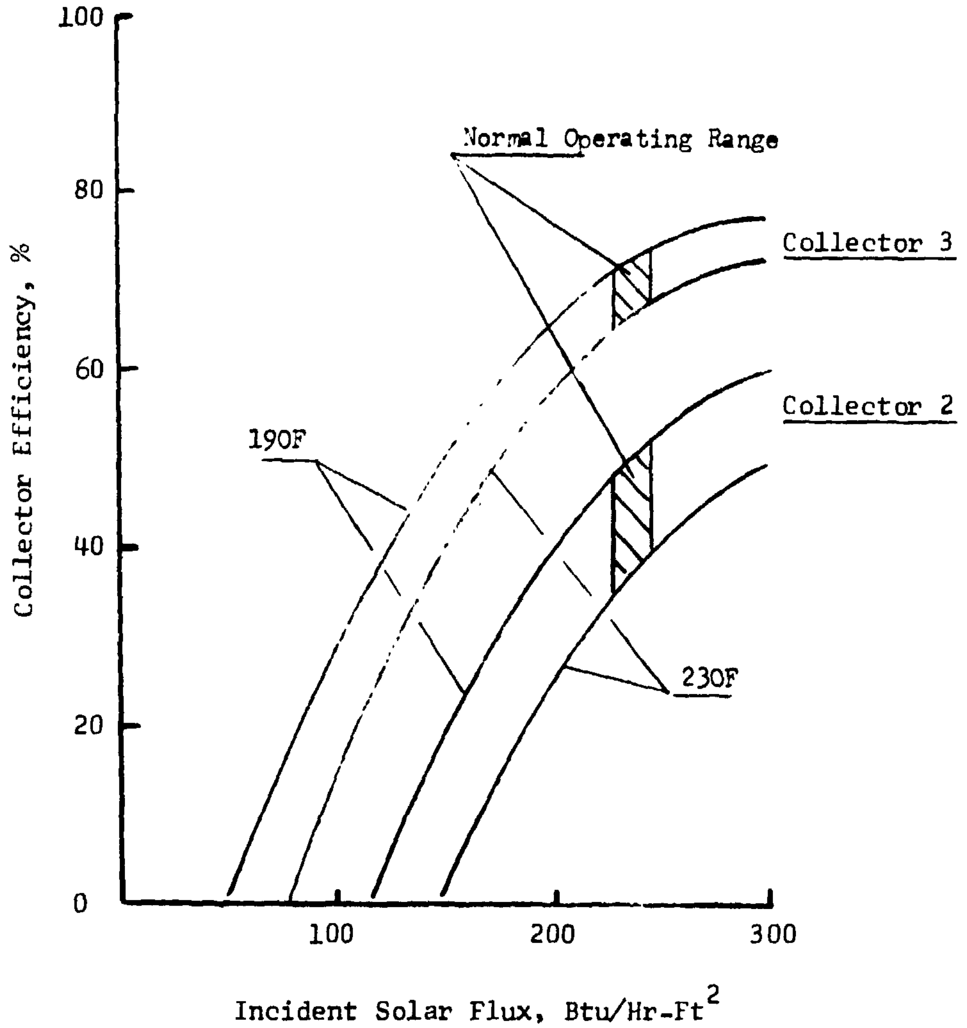


Figure 10

SOLAR RADIATION AT LANGLEY FOR 30° TILT

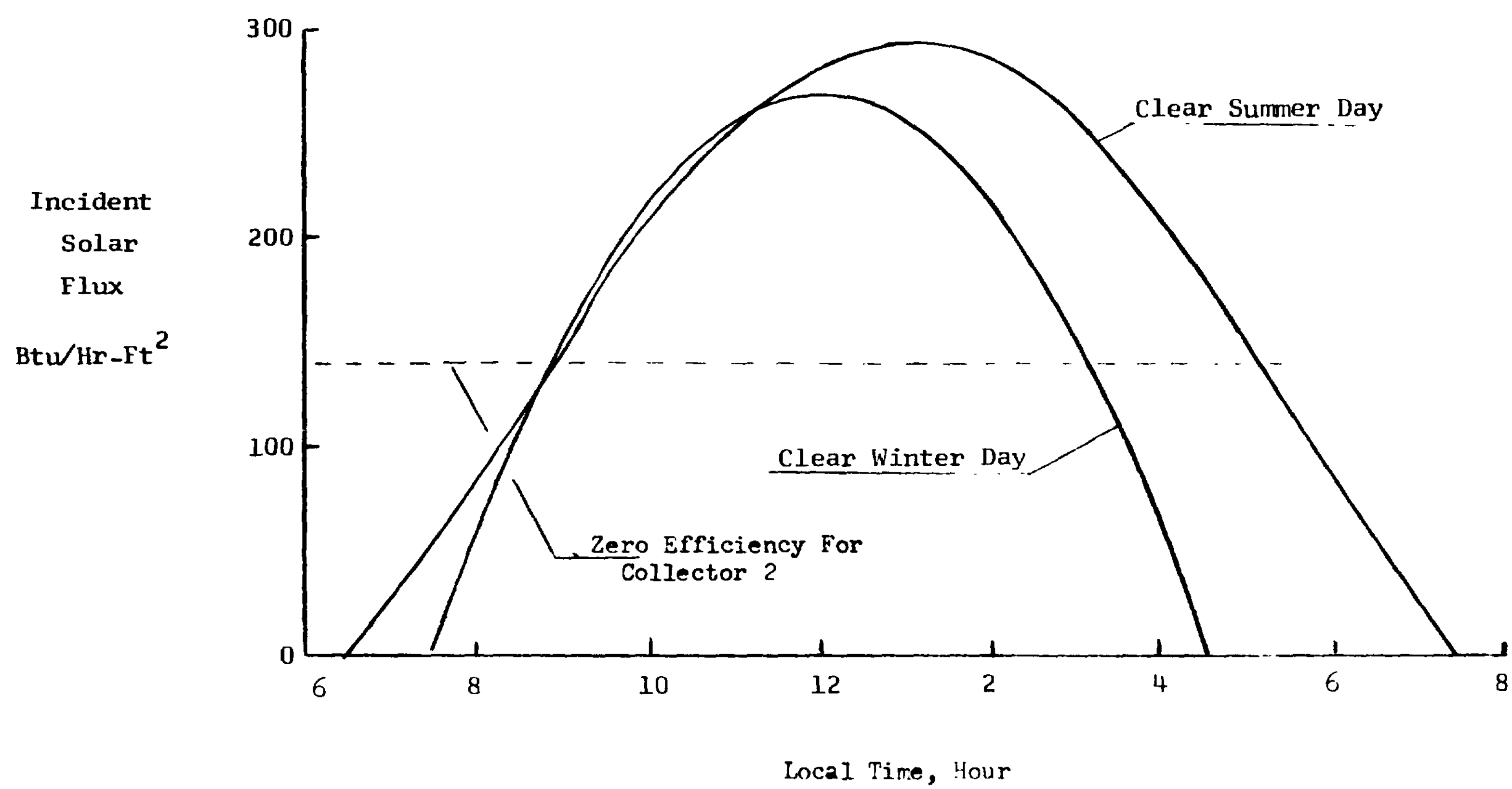


Figure 11

LANGLEY SEB

SOLAR ENERGY COLLECTED

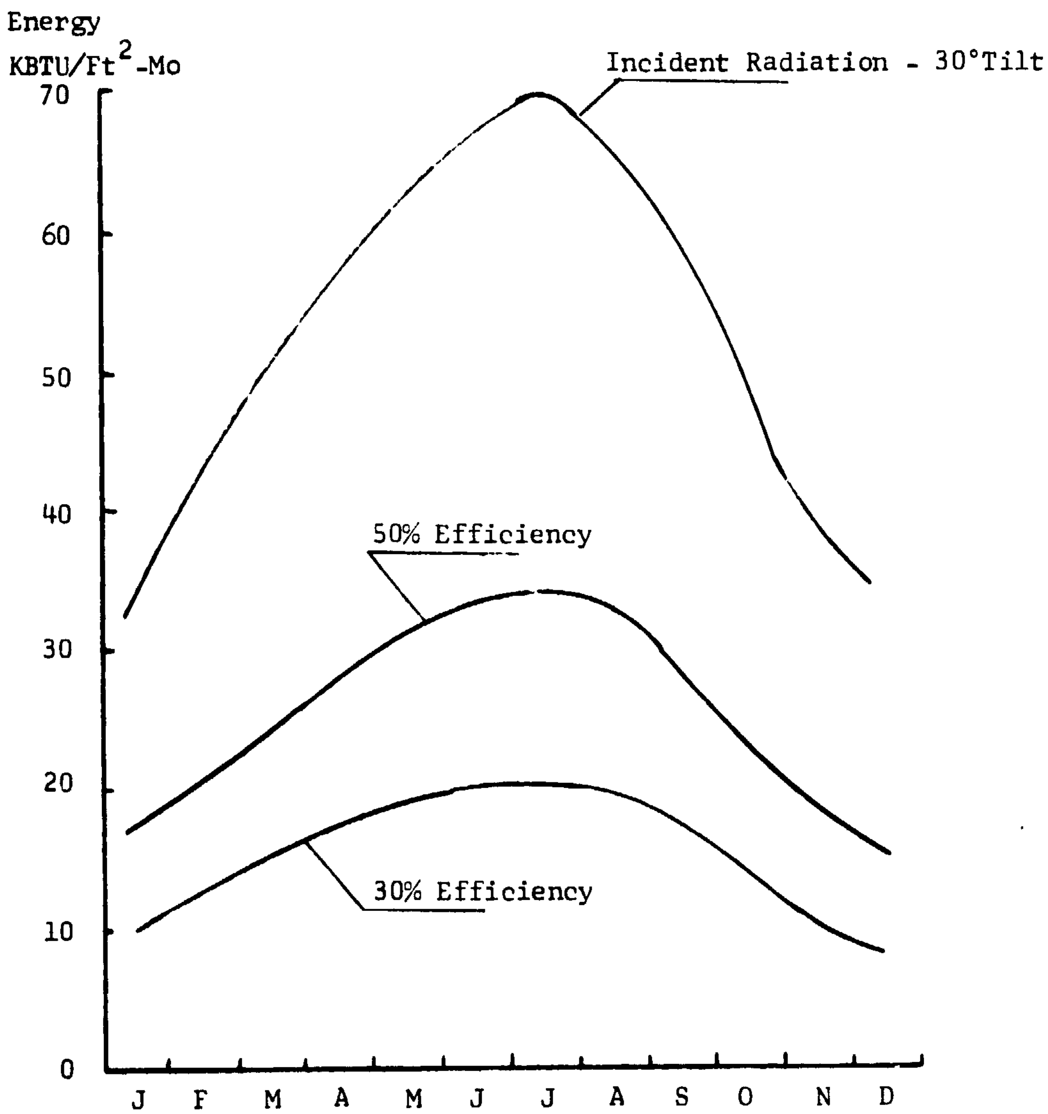


Figure 12

LANGLEY SEB

ENERGY MATCH

Collector Area - 15,000 Ft^2

Collector Tile - 30°